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Preliminary Experimental Study on Effectiveness of Aquatic Vegetation on Sediment Transport Capacity

(Kajian Eksperimen Awal pada Keberkesanan Vegetasi Akuatik terhadap Kapasiti Pengangkutan Sediment)

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ABSTRACT

Vegetation affects sediment transport by obstructing the flow and changing the turbulence characteristics. Common sediment transport equations are not applicable to situations with submerged vegetation. A laboratory experiment was carried out in which flow, vegetation, and sediment transport were measured in an open channel model with a 240 cm long section of 50 cm high x 50cm width with submerged vege-tation in a sand bed. Measured data from various vegetation density and height were analyzed to obtain estimates of the trapping efficiency. Results show an increment of the trapping efficiency with 86.7% and 94.2% reduction in sediment concentration compared to a case without vegetation.

Keywords: Vegetation; sediment transport; sediment trapping; efficiency; suspended sediment

ABSTRAK

Tumbuhan mempengaruhi pengangkutan sedimen dengan menghalang aliran dan mengubah ciri turbulensi. Persamaan pengangkutan sedimen biasa tidak boleh digunakan untuk situasi dengan tumbuh-tumbuhan terendam. Satu eksperimen makmal dilakukan di mana aliran, tumbuhan, dan pengangkutan sedimen diukur dalam model saluran terbuka dengan panjang 240 cm dengan panjang 50 cm x lebar 50cm dengan tumbuhan terendam di dasar pasir. Data yang diukur dari pelbagai kepadatan dan tinggi tumbuhan dianalisis untuk mendapatkan anggaran kecekapan perangkap. Hasil menunjukkan peningkatan kecekapan memerangkap dengan penurunan kepekatan sedimen 86.7% dan 94.2% berbanding dengan kes tanpa tumbuh-tumbuhan.

Kata kunci: Tumbuh-tumbuhan; pengangkutan sedimen; memerangkap sedimen; kecekapan; enapan terampai

INTRODUCTION

Suspended sediment has long been recognized as important contaminant affecting water resources. Besides its direct role in determining water clarity, bridge scour, and reservoir shortage, sediment serves as a vehicle for the transport of many binding contaminants, including nutrients, trace metals, semi-volatile organic com-pounds, and numerous pesticides. According to the Malaysian Department of Environment's (DOE) 2002, 52 river basins were polluted with suspended solid resulting from poorly planned and un-controlled land clearing activities. Sediment has been identified as a medium for the transport and sequestration of organic carbon. If the suspended load has high organic carbon content, the biochemical oxygen demand will be raised, and conversely, the dissolved oxygen levels will decrease.

Rivers play an important role in the transport of water, sediment, nutrition, crops, and so on, as a dynamic ecosystem. Rivers and their neighbourhoods have now become ideal habitats for plants and animals. Meanwhile, a significant number of landscape trees and shrubs have been planted on both sides of the river with the idea of ecological rivers. However, flow resistance, velocity profile, and turbulence structure can be altered by the presence of aquatic vegetation (Ghisalberti & Nepf 2002, 2004; Huai et al. 2019; Katul et al. 2011; Pan et al. 2019; Yang et al. 2015; Zhao et al. 2019). These developments have a great impact on the transport of sediments. However, the dynamic interactions between the effects of vegetation, water flow, and sediment movement have not been clearly explained. In addition, sediment transport has a major effect on the hydraulic structures' function and morphology, bank erosion, sediment deposition, and river channel evolution (Curran & Hession 2013; Huang et al. 2019; Masoodi et al. 2019; Samadi et al. 2009,; Samadi et al. 2011; Wu et al. 2005). Hence, it is interesting to examine interactions to minimize the probability of flooding and to provide better management of the river.

It is known that the vegetation will slow down the water flow velocities and enhances sedimentation. The sedimentation resulting from soil erosion degrades the surface water environment. Many chemical pollutants and pathogens tend to accumulate in sediment, disturbing surface water quality. Research efforts have been put into the effects of vegetation on hydraulic roughness (Vincent et al. 2012; Chao et al. 2015; Andrés et al. 2014) but the effects of vegetation on hydraulic roughness (Baptist 2003; Gary et al. 1994; Yuri 2012; Nepf et al. 2000; Stephan 2002) but the effect of vegetation on the suspended sediment transport.

The aim of this study are to investigate the effect of size, and density of the selected vegetation on trapping suspended sediments in open channel flow. The relationship between trapping efficiency with vegetation height, vegetation density and time were also observed.

METHODOLOGY

Experiments were conducted in an open channel model with a 240 cm long by 50 cm high x 50 cm width with submerged vegetation named Cabomba Caroliniana in a sand bed. Cabomba caroliniana is an aquatic perennial herbaceous plant. This species grows rooted in the mud of stagnant to slow-flowing water, including streams, smaller rivers, lakes, ponds, sloughs, and ditches (Wikipedia 2018). Cohesionless bed sediment was used as a channel bed. A 10 cm thick layer of sand was distributed evenly in the open channel section and the slope of the channel is 1:1000 referring to the low land of the real river. There have three sections in the open channel model; inlet, open channel, and outlet where water is flowing through three sections of the channel. The open channel setup is shown in Figure 1.

The tests conditions were defined based on velocity of flow, sediment concentration, vegetation density, vegetation height, and water depth, respectively. Therefore, impact of vegetation coverage and on the suspended sediment trapping efficiency was studied in three different densities (12%, 25%, and 50%) while vegetation height was tested at 10 cm, 20 cm, and 30 cm. The total suspended sediment or sediment concentration was also observed and the test was performed in a laboratory.

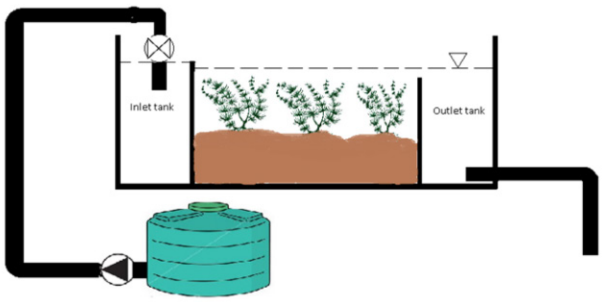

FIGURE 1. Side view of the experimental open channel model

During experiment, water in the storage tank was pumped and flowed to the open channel model. The discharge from storage tank was measured by flow meter. The 50 ml of water sample were taken before and after the water flowed through the vegetation. The procedure was repeated at 5 min, 10 min, and 15 min. The sediment trap efficiency (e) is evaluated as

$$e = (m_{in} - m_{out})/m_{in} = 1 - m_{out}/m_{in} \quad (1)$$

where, m_{in} = mass of incoming suspended sediments and m_{out} = mass of suspended sediments pass through flow.

RESULTS AND DISCUSSION

EFFECT OF VEGETATION DENSITY ON SEDIMENT TRANSPORT

The results of the effect of vegetation density on trapping suspended sediment were summarized in Table 1. From the observation, the number of vegetation plays a role in determining the trapping efficiency of suspended sediment in each of time recorded. This can be proved when the efficiency of trapping at 50% of vegetation density showed the highest reading with 82.9%, 88.6%, and 94.3% in 15, 10 and, 5 minutes of time recorded at 30 cm of vegetation height. This might be when the number of vegetation in the channel increases, the roughness coefficient also increases in the water. From Table 1, when the vegetation density increased from 12% to 25%, the trapping efficiency was increased 12.24%, while the increment of vegetation density from 25% to 50%, the sediment trapping efficiency majorly increased with 22.47% in 5 minutes. Meanwhile, the lowest trapping efficiency at 12% density of vegetation present 62%, 65.7%, and 68.6% of the same time recorded.

The results in Figure 2 shows that smaller vegetation coverage resulted in more erosion and sedimentation. At larger vegetation coverage, the changes in bed elevation becomes smaller. This result confirms that vegetation decreases velocity of flow and increases flow resistance and bed shear stress in vegetated area. Yang et al. (2014) also found the same phenomenon of the effect of vegetation density on sediment transport and they had concluded that high density vegetation coverage results in less erosion.

TABLE 1. The trapping efficiency of sediment trapping vegetation on different density at 30 cm height of vegetation

Percentage of vegetation coverage	Time (min)	Vegetation height (cm)	Sediment trapping efficiency (%)
0%	5	-	0.57
	10	-	3.7
	15	-	9.1
12 %	5	30	0.69
	10	30	0.66
	15	30	0.62
25 %	5	30	0.77
	10	30	0.74
	15	30	0.71
50%	5	30	0.94
	10	30	0.89
	15	30	0.83

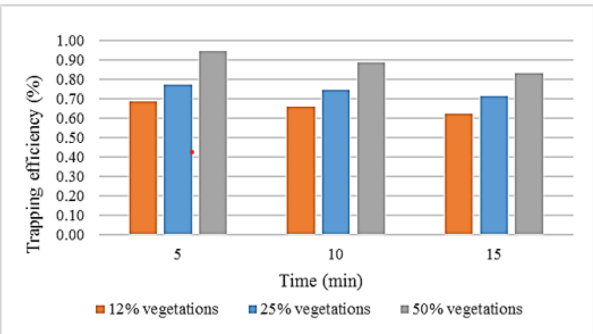

FIGURE 2. The effect of different density of vegetation on the trap-ping efficiency at 30 cm of vegetation height and at different of time recorded

EFFECT OF VEGETATION HEIGHT ON SEDIMENT TRANSPORT

Table 2 shows the effect of suspended sediment trapping efficiency on all of vegetation height at each vegetation density. Vegetation density of 12% depict the highest trapping efficiency at 30 cm of vegetation height, with 0.69 at 5 minutes, 0.66 at 10 minutes, and 0.63 at 15 minutes. Next, followed by 20 cm of vegetation height where the trapping efficiency were 0.49, 0.43, and 0.25 at 5, 10, and 15 minutes, respectively. The lowest trapping efficiency was recorded at 10 cm of vegetation height with 0.29, 0.20, and 0.11.

Next, for 25% and 50% vegetation density, similar pattern was found where the highest sediment trapping efficiency occurred at 5 minutes of time recorded. The results are shown in Figure 3. This is maybe due to the process of settlement of sediment that just started compared to the test duration of 10 and 15 minutes. Long test duration will allow the sediment deposited at the channel bed, thus giving lower values for long duration of time. However, at low vegetation height (10 cm), the results show high sediment trap efficiency for each percentage vegetation coverage. This might be due to the shallowness of plants that make the suspended sediment at the top of the vegetation layer to still exist and during the sample was taken it would give higher value of trapping efficiency after the samples were dried and weighted.

TABLE 2. Suspended sediment trapping efficiency for different vegetation height at all of vegetation densities

Vegetation density	Vegetation height (cm)	Time (min)	Sediment trapping efficiency
		5	0.29
	10	10	0.20
		15	0.11
		5	0.49
12%	20	10	0.43
		15	0.25
		5	0.69
	30	10	0.66
		15	0.63
		5	0.38
	10	10	0.30
		15	0.27
		5	0.71
25%	20	10	0.60
		15	0.56
		5	0.77
	30	10	0.74
		15	0.64

continue...

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		5	0.45
	10	10	0.38
		15	0.30
		5	0.91
50%	20	10	0.83
		15	0.77
		5	0.94
	30	10	0.89
		15	0.83

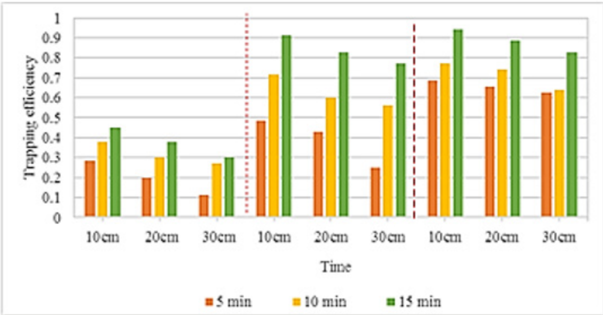

FIGURE 3. Suspended sediment trapping efficiency at different vegetation height in each vegetation density

TOTAL SUSPENDED SOLID

Total suspended solid is used to access the trapping efficiency of suspended sediment in the sample as a water quality parameter in the flume model. All of the sediment particle that retain on filter paper are called total suspended solid. The total suspended solid for the suspended sediment water for non-vegetation in this study was 0.35 mg/L. Table 3 summarized the results of Total Suspended Solid (TSS) experiment that had been conducted in the laboratory. It is showed that the value of the concentration of total suspended solid decreased when the vegetation density and vegetation height were increased. The lowest total suspended solid was 0.02 mg/L recorded at 50% of vegetation density with 30 cm height within 15 minutes of time recorded. While the highest value of total suspended solid was 0.31 mg/L at 12% vegetation density, 10 cm height within 5 minutes of time recorded.

TABLE 3. Total suspended solid for different vegetation height and density

Vegetation density	Vegetation height,cm	Total Suspended Solid (mg/L)		
		5 min	10 min	15 min
12%	10	0.31	0.28	0.25
	20	0.26	0.20	0.18
	30	0.13	0.12	0.11
25%	10	0.15	0.12	0.10
	20	0.12	0.11	0.09

continue...

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	30	0.12	0.09	0.08
50%	10	0.12	0.09	0.07
	20	0.08	0.06	0.03
	30	0.06	0.04	0.02

CONCLUSIONS

The vegetation, sediment, and water flow are major parts in the aquatic environment. Sediment trapping in vegetative area was experimentally studied in a flume with different simulated vegetation densities, vegetation height, and time. The study shows that the vegetation densities and height were the main factors in determining the trapping efficiency, while time had a minor effect on the trapping efficiency for the range of conditions investigated. When the vegetation densities increased from 12% to 50%, the trapping efficiency increased to about 86.7%. As the vegetation height increased, the trapping efficiency decreased when the data were compared with time in the same vegetation coverage. Meanwhile, the result on total suspended solid show 94.2% reduction in sediment concentration compared to a case without vegetation.

All the test in this study were conducted in submerged shallow overland flow with low flow rates and sediment concentrations. Thus, the results obtained only valid for shallow, uniform flow, submerged vegetation with sediment concentrations less than the transport capacity of the flow to the vegetative area.

FUTURE RESEARCH

Even though some progress have been made on the studies of the interactions between the sediment transport, water flow, and vegetation, there is still a lot of work to do in the future. In this context, the study technique of the vegetation, flow, and sediment transport should be improved to provide a theoretical basis for their interactions. Besides that, the objective of the study also needs to be expanded. It is crucial to use all existing methods concurrently, including the observations at field, the experiments of flume, the chemistry environmental analyses and the numerical simulations, in order to observe the interactions among the vegetation, sediment, and water flow. In addition, the results obtained are expected to be used in the engineering practice and management.

Next, focus on the effects of the water flow and water level variations on the growth and reproduction of aquatic plants are also one of the important parts. In the aquatic environment, the suitable density of the vegetation is very important. The selection of the optimum planting density of the vegetation to keep a balance between the flood discharge capacity and a healthy water environment need to be found. Furthermore, the pollutants transformation and migration in the "sediment-vegetation-water flow" system need to be explored in the future.

In addition, the mechanisms of the suspended particle size change under different hydrodynamic conditions in vegetated and non-vegetated areas are some difficult problems that need to be solved and more efforts is required from researchers. Meanwhile, the numerical simulations of the sediment transport in vegetated regions also need to be further investigated.

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DECLARATION OF COMPETING INTEREST

None

REFERENCES

Luna, A.V., Crosato, A. & Uijttewaal, W.S.J. 2014. Effects of vegetation on flow and sediment transport: Comparative analyses and validation of predicting models. *Earth Surface Processes and Landforms* 40(2): 157-176.

Baptist, M.J. 2003. A flume experiment on sediment transport with flexible submerged vegetation. *International Workshop on Riparian Forest Vegetated Channels: Hydraulic, Morphological and Ecological Aspects,* 20 – 22 February, Trento, Italy.

Chao W., Sha-sha Z., Pei-fang W. & Jun H. 2015. Interactions between vegetation, water flow and sediment transport: A review. *Journal of Hydrodynamics* 27(1): 24-37.

Curran, J.C, W.C. Hession. 2013. Vegetative impacts on hydraulics and sediment processes across the fluvial system. *J. Hydrol.* 505: 364-376.

Gary, E.F. & Brad, R.H 1994. Effects of vegetation on hydraulic roughness and sedimentation in wetlands. *Technical Note SD-CP-2.2 Army Engineer Waterways Experiment Station.*

Ghisalberti, M. & H.M. Nepf. 2002. Mixing layers and coherent structures in vegetated aquatic flows. *J. Geophys. Res.* 107(C2): 3011.

Ghisalberti, M. & Nepf, H.M. 2004. The limited growth of vegetated shear layers. *Water. Resour. Res.* 40.

Huai, L., Yang, W.J., Wang, Y., Guo, T. & Wang, Y.C. 2019. Predicting the vertical low suspended sediment concentration in vegetated flow using a random displacement model. *J. Hydrol.* 578.

Huang, C.C., H.T. Fang, H.C. Ho & B.C. Jhong 2019. Interdisciplinary application of numerical and machine-learning-based models to predict half-hourly suspended sediment concentrations during typhoons. *J. Hydrol.* 573: 661-675.

Katul, G.G., Poggi, D. & Ridolfi, L. 2011. A flow resistance model for assessing the impact of vegetation on flood routing mechanics.

Masoodi, A., M.R. Majdzadeh Tabatabai, A. Noorzad, & A. Samadi. 2019. Riverbank stability under the influence of soil dispersion phenomenon. *J. Hydrol. Eng*. 24: 05019001.

Nepf, H.M. & Vivoni, E.R. 2000. Flow structure in depth-limited, vegetated flow. *Journal of Geophysical Research* 105(12): 28,547-28,557.

Pan, Y., Z. Li, K. Yang & D. Jia. 2019. Velocity distribution characteristics in meandering compound channels with one-sided vegetated floodplains. *J. Hydrol.* 578.

Samadi, A., E. Amiri-Tokaldany & S.E. Darby. 2009. Identifying the effects of parameter uncertainty on the reliability of riverbank stability modelling. *Geomorphology* 106: 219-230.

Samadi, A., E. Amiri-Tokaldany, M.H. Davoudi & S.E. Darby. 2011. Identifying the effects of parameter uncertainty on the reliability of modeling the stability of overhanging, multi-layered, river banks. *Geomorphology* 134: 483-498.

Stephan, U. & Gutknecht, D. 2002. Hydraulic resistance of submerged flexible vegetation. *Journal of Hydrology* 269: 27-43.

Vincent S.N., Constantinescu, S., Sean, B. & Panayiotis, D. 2012. Effect of vegetation on turbulence, sediment transport and stream morphology. *J. Hydraul. Eng.* 138: 765-776

Water Resour. Res., 47 (2011), pp. 1-15, 10.1029/2010WR010278

Wikipedia. 2018. https://en.wikipedia.org/wiki/Cabomba_caroliniana. (accessed 8 August 2018)

Wu, W., Shields, F.D., Bennett, S.J. & Wang, S.S.Y. 2005. A depth-averaged two-dimensional model for flow, sediment transport, and bed topography in curved channels with riparian vegetation. *Water Resour. Res.* 41: 1-15.

Yang, B. & Jennifer, G.D. 2014. Simulating unsteady flow and sediment transport in vegetated channel network. *Journal of Hydrology* 515: 90–102.

Yang, J.Q., Kerger, F. & Nepf, H.M. 2015. Estimation of the bed shear stress in vegetated and bare channels with smooth beds. *Water Resour. Res.* 51: 3647-3663.

Yuri. 2012. Interference of Hydraulic Roughness Generated by Unsubmerged Vegetation on Sediment Transport in Capibaribe River. (Master diss., University of Pernambuco)

Zhao H., J. Yan, S. Yuan, J. Liu & J. Zheng. 2019.

Effects of submerged vegetation density on turbulent flow characteristics in an open channel. *Water* 11: 2154.